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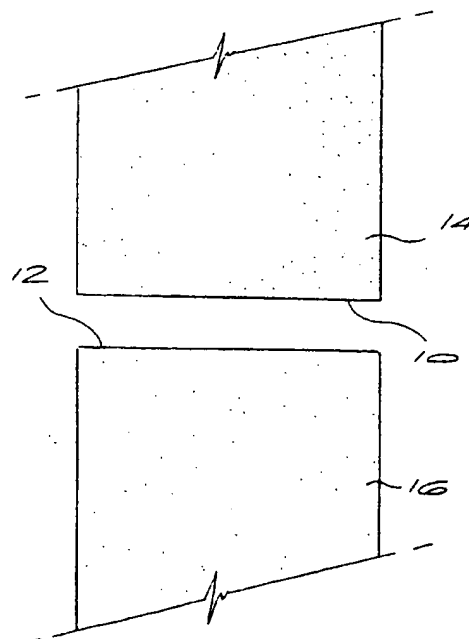
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54 **Bearing assembly.**

57 A diamond-bearing assembly comprises opposed diamond-bearing surfaces (10, 12), at least one of which is free of any Group VIII metals such as cobalt. Preferably, each of the surfaces (10, 12) is provided by a surface of a diamond compact (14, 16), such diamond compact containing substantial diamond-to-diamond bonding, and a second phase which contains silicon in the form of silicon and/or silicon carbide.



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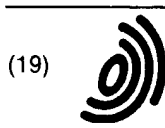
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# EUROPEAN SEARCH REPORT

Application Number  
EP 94 30 2164

| DOCUMENTS CONSIDERED TO BE RELEVANT  |  |   |  |
|--|--|---|--|
| Category   | Citation of document with indication, where appropriate, of relevant passages  | Relevant to claim                               | CLASSIFICATION OF THE APPLICATION (Int. Cl. 5) |
| A, D   | US-A-4 620 601 (D. D. NAGEL)<br>* claim 1 *  | 1   | F16C33/04                                      |
| A, D   | US-A-4 560 014 (B. A. GECZY)<br>* claim 4 *  | 1   |  |
| A, D   | US-A-5 092 687 (D. R. HALL)<br>* claim 1 *   | 1   |  |
| X  | PATENT ABSTRACTS OF JAPAN<br>vol. 12 no. 347 (M-743) [3194], 19<br>September 1988<br>& JP-A-63 106420 (CANON) 11 May 1988,<br>* abstract * | 1, 5  |  |
| A  | EP-A-0 022 285 (PHILIPS PATENTVERWALTUNG)<br>* claim 1 *   | 1, 5  |  |
| A, D   | US-A-4 151 686 (M. LEE ET AL.)<br>* claim 1 *  | 2, 3  |  |
| A, D   | US-A-4 793 828 (R. P. BURNAND)<br>* claim 1 *  | 2, 3  |  |
| A, D   | US-A-4 224 380 (H. P. BOVENKERK ET AL.)<br>* claim 1 *   | 4   |  |
| A  | EP-A-0 300 699 (SMITH INTERNATIONAL)<br>* column 6, line 8 - line 18 *   |   |  |
| The present search report has been drawn up for all claims   |  |   |  |
| Place of search<br>BERLIN  |  | Date of completion of the search<br>23 May 1995 | Examiner<br>Sutor, W                           |
| <p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone<br/>Y : particularly relevant if combined with another document of the same category<br/>A : technological background<br/>O : non-written disclosure<br/>P : intermediate document</p> <p>T : theory or principle underlying the invention<br/>E : earlier patent document, but published on, or after the filing date<br/>D : document cited in the application<br/>L : document cited for other reasons<br/>&amp; : member of the same patent family, corresponding document</p> |  |   |  |

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(54) **Bearing assembly**

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Dispositif de palier

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(56) References cited:  
**EP-A- 0 022 285**                      **EP-A- 0 300 699**  
**US-A- 4 151 686**                      **US-A- 4 224 380**  
**US-A- 4 560 014**                      **US-A- 4 620 601**  
**US-A- 4 793 828**                      **US-A- 5 092 687**

• **PATENT ABSTRACTS OF JAPAN vol. 12 no. 347**  
**(M-743) [3194], 19 September 1988 & JP-A-63**  
**106420 (CANON) 11 May 1988,**

**EP 0 617 207 B1**

Note: Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

**Description****BACKGROUND OF THE INVENTION**

This invention relates to bearing assemblies.

Diamond-bearing assemblies are known and are used in various applications. One application of a diamond-bearing assembly is a downhole motor used in the drilling industry.

In diamond-bearing assemblies, e.g. known from JP-A-63 106 420 and US-A- 4 620 601, the opposed bearing surfaces of the assembly are both made of a diamond material. The diamond material is polycrystalline diamond or PCD. This diamond material is also known in the art as a diamond compact. Such material is used because of its long wearing life and its ability to carry substantial loads. The polycrystalline diamond which has been used for diamond-bearing assemblies is that known in the art as Syndite®, Syndrill® or Strata-pax®. This polycrystalline diamond material contains substantial amounts of Group VIII metals such as cobalt, iron or nickel. Reference in this regard may be made to US-A- 4 620 601, column 12 lines 30 to 37, and US-A- 4 560 014, column 9 lines 29 to 44.

US-A-5 092 687 describes diamond-bearing assemblies having opposed diamond-bearing surfaces. The diamond-bearing surfaces are provided by cemented tungsten carbide in which synthetic diamonds are bonded - column 3 lines 49 to 51. Cemented tungsten carbide has a Group VIII metal such as cobalt, nickel or iron as its binder.

It has been found that where a diamond-bearing assembly utilises a diamond material containing a Group VIII metal, as in the references described above, the friction behaviour of the contacting-bearing surfaces tends to become quite unpredictable during high contact pressures. In some cases, rapid seizure of the bearing assembly occurs without adequate warning. This phenomenon is believed to be caused by a Group VIII-rich tribofilm which forms on the diamond surfaces during use of the bearing assembly.

**SUMMARY OF THE INVENTION**

According to the present invention, a bearing assembly comprises opposed diamond bearing surfaces, both of which are free of any Group VIII metal.

The term "free of any Group VIII metal" means that there will be substantially no Group VIII metal in that surface, although trace amounts of Group VIII metals may be present without resulting in a deleterious effect. Group VIII metals include cobalt, iron and nickel.

**DESCRIPTION OF THE DRAWINGS**

Figures 1 and 2 illustrate diagrammatic sectional views of opposed diamond-bearing surfaces of two embodiments of bearing assemblies of the invention.

**DESCRIPTION OF EMBODIMENTS**

The invention provides a bearing assembly comprising opposed diamond bearing surfaces. The bearing assembly may be any known in the art. The invention has particular application to diamond thrust bearing assemblies for a downhole motor as used in the drilling industry. Examples of such bearing assemblies are described, for example, in US-A-4 560 014 and EP-A-0 595 630 European Patent Application No. 93308591.2). It has been found that the absence, or substantial absence, of Group VIII metal in the opposed diamond-bearing surfaces achieves a low friction coefficient of no greater than 0, 1 and the ability to carry substantial loads equivalent to contact pressures of 68MPa or greater.

One or each diamond-bearing surface may be provided by a surface of any one of various diamond bodies. One such diamond body, and the preferred diamond body, is that which contains substantial diamond-to-diamond bonding and a second phase consisting essentially of silicon, the silicon being in the form of silicon and/or silicon carbide. The diamond content will generally be 80 to 90 percent by volume and the diamond-to-diamond bonding will generally be such as to form a coherent, skeletal mass. The silicon second phase will generally be present in an amount of 10 to 20 percent by volume. Examples of such diamond bodies can be found described in US-A- 4 151 686 and US-A- 4 793 828. Further, an example of such a body is that sold under the trade name Syndax®.

An example of another suitable diamond body which can provide a surface free, or substantially free, of Group VIII metal is one which contains self-bonded diamond particles in an amount of 70 percent to 95 percent by volume, and a network of interconnected, empty pores dispersed through the body. The body may contain a minor amount of metallic phase infiltrated substantially uniformly throughout the body. Such a diamond body is known as a leached diamond compact and an example is described in US-A- 4 224 380.

The diamond surface free of Group VIII metal may also be provided by the surface of a diamond film produced by chemical vapour deposition (CVD). CVD diamond films are produced on substrates such as silicon carbide, tungsten carbide and the like. The production of CVD diamond films is well known in the art and involves dissociating a gaseous carbon compound to produce carbon atoms, ions or radicals which are allowed to deposit on a surface of a substrate to form the diamond film.

The diamond surface free of Group VIII metal may also be provided by the surface of a diamond compact, produced under diamond synthesis conditions, which comprises at least 70 percent by volume, preferably 80 to 90 percent by volume, diamond, substantial diamond-to-diamond bonding and a second phase which consists of an alkaline earth metal carbonate, particularly calcium carbonate.

Two embodiments of the invention will now be described with reference to the accompanying drawings. Referring first to Figure 1, there is shown a bearing assembly comprising opposed bearing surfaces 10 and 12. The bearing surfaces 10 and 12 each form one surface of diamond compacts 14 and 16. The diamond compacts are both free of any Group VIII metal, so that the bearing surfaces 10, 12 are free of such metal.

Referring now to Figure 2, the opposed bearing surfaces of a bearing assembly are defined by surfaces 20 and 22. Bearing surface 20 forms one surface of a diamond compact 24. Bearing surface 22 forms one surface of a diamond end zone 26 of a body 28. The diamond end zone 26 may be constituted by leached diamond compact, Syndax® or by a layer of CVD diamond. The zone 26 is bonded to a substrate 30 which may be a diamond-containing body such as a diamond compact, or it may be made of a different material, e.g. cemented carbide.

In another embodiment (not shown) the diamond compact 24 can be replaced by a composite diamond-containing body similar to that of the body 28.

A series of tests were carried out using various diamond bearing surfaces. A pin-on-disc tribometer was utilised to generate a unidirectional sliding motion. In the machine, the one component of the sliding couple (pin) was fixed in a sample holder on a cantilever load arm. The pin was allowed to slide on a horizontal disc or ring on a turntable drive by a fixed or variable speed motor. The load on the pin could be varied and was applied by means of dead weights on the load arm.

The products used were Syndrill®, a diamond compact or PCD containing about 10 percent by mass of cobalt uniformly dispersed or distributed through the bonded diamond mass, and Syndax®, a diamond body containing substantial diamond-to-diamond bonding and a second phase consisting essentially of silicon, the silicon being in the form of silicon and/or silicon carbide. Various tests were carried out in which both the pin and disc were made of Syndrill®, both pin and disc were made of Syndax® and one of the pin and disc made of Syndrill® and the other of Syndax®.

In a dry, unlubricated, sliding test the lowest friction coefficient was achieved when both the pin and disc were made of Syndax®. It was found that such an arrangement showed a low friction coefficient of no greater than 0,1 and a high load carrying capacity of at least 4300N which is equivalent to a contact pressure of at least 68MPa. This is in marked contrast to the results achieved when both the pin and disc were made of Syndrill® which showed much higher friction coefficients of 0,13 to 0,26 and a lower load carrying capacity (approximately 2800N which is equivalent to a contact pressure of 44MPa). In this latter case, a cobalt-rich tribofilm was found to have formed on the sliding surfaces. This, it is believed, was the cause of the high friction coefficients. Removal of such tribofilms, e.g. using HCl, temporarily reduced the friction coefficient until the film reformed.

In a further series of tests, the pin was made of Syndax® and the disc Syndrill® and vice versa. Again, dry, unlubricated, sliding conditions were used. It was found that this combination showed lower friction coefficients than that with the Syndrill/Syndrill® combination. Further, although a tribofilm was observed between the bearing surfaces, this film contained primarily silicon and only a small amount of cobalt. Thus, there was evidence that the silicon suppressed formation of the deleterious cobalt-rich tribofilm leading to a lower friction coefficient.

A similar series of tests were carried out using water as a lubricant. The Syndrill/Syndrill® couple was found to exhibit a poor load carrying capacity of only 2800N although the friction coefficients obtained were low and of the order of 0,1. The Syndax/Syndax® couple exhibited much the same behaviour as in the unlubricated, sliding tests, i.e. low friction coefficients of no greater than 0,1 and high load carrying capacities of greater than 4300N which is equivalent to contact pressures of greater than 68MPa.

#### Claims

1. A bearing assembly comprising opposed diamond-bearing surfaces (10, 12), characterized in that both diamond-bearing surfaces (10,12) are free of any Group VIII metal.
2. A bearing assembly according to claim 1 wherein one of the opposed diamond-bearing surfaces is provided by the surface (10, 12) of a diamond body (14, 16) containing substantial diamond-to-diamond bonding and a second phase consisting essentially of silicon, the silicon being in the form of silicon and/or silicon carbide.
3. A bearing assembly according to claim 1 wherein each of the opposed diamond-bearing surfaces is provided by a surface (10, 12) of a diamond body (14, 16) containing substantial diamond-to-diamond bonding and a second phase consisting essentially of silicon, the silicon being in the form of silicon and/or silicon carbide.
4. A bearing assembly according to claim 1 wherein one or each of the opposed diamond-bearing surfaces is provided by the surface (22) of a diamond body (26) which comprises self-bonded diamond particles present in an amount of 70 percent to 95 percent by volume of the body, and a network of interconnected, empty pores dispersed through the body.
5. A bearing assembly according to claim 1 wherein one or each of the opposed diamond-bearing surfaces is provided by a surface (22) of a CVD dia-

mond film (26).

6. A downhole drill motor comprising a bearing assembly in accordance with any one of claims 1 to 5 in the form of a thrust bearing.

#### Patentansprüche

1. Lagervorrichtung mit zwei gegenüberliegenden Diamant-Lageroberflächen (10, 12), **dadurch gekennzeichnet**, daß beide Diamant-Lageroberflächen (10, 12) frei von Metall der Gruppe VIII sind. 10
2. Lagervorrichtung nach Anspruch 1, bei der eine der gegenüberliegenden Diamant-Lageroberflächen durch die Oberfläche (10, 12) eines Diamantkörpers (14, 16) gebildet ist, der eine wesentliche Verbindung von Diamant zu Diamant und eine zweite Phase enthält, die im wesentlichen aus Silizium besteht, wobei das Silizium in der Form von Silizium und/oder Siliziumkarbid vorliegt. 15 20
3. Lagervorrichtung nach Anspruch 1, bei der jede der gegenüberliegenden Diamant-Lageroberflächen durch eine Oberfläche (10, 12) eines Diamantkörpers (14, 16) gebildet ist, der eine wesentliche Verbindung von Diamant zu Diamant und eine zweite Phase enthält, die im wesentlichen aus Silizium besteht, wobei das Silizium in der Form von Silizium und/oder Siliziumkarbid vorliegt. 25 30
4. Lagervorrichtung nach Anspruch 1, bei der eine oder jede der gegenüberliegenden Diamant-Lageroberflächen durch die Oberfläche (22) eines Diamantkörpers (26) gebildet ist, der selbstbindende Diamantteilchen aufweist, die in einer Menge von 70 bis 95 Volumenprozent des Körpers vorliegen, und ein Netzwerk von miteinander verbundenen, leeren Poren, die durch den Körper hindurch fein verteilt sind. 35 40
5. Lagervorrichtung nach Anspruch 1, bei der eine oder jede der gegenüberliegenden Diamant-Lageroberflächen durch eine Oberfläche (22) eines CVD-Diamantfilms (26) gebildet ist. 45
6. Motor zum Bohren lochabwärts mit einer Lagervorrichtung gemäß irgendeinem der Ansprüche 1 bis 5, in der Form eines Drucklagers. 50

#### Revendications

1. Dispositif de support comprenant des surfaces de diamant opposées (10, 12), caractérisé en ce que les deux surfaces de support de diamant (10, 12) sont exemptes d'un quelconque métal du groupe 55

VIII.

2. Dispositif de support suivant la revendication 1, caractérisé en ce qu'une des surfaces de support de diamant opposées est prévue par la surface (10, 12) d'un corps de diamant (14, 16) contenant une liaison sensible diamant sur diamant et une seconde phase constituée essentiellement de silicium, le silicium étant sous la forme de silicium et/ou de carbure de silicium. 5
3. Dispositif de support suivant la revendication 1, caractérisé en ce que chacune des surfaces de support de diamant opposées est prévue par une surface (10, 12) d'un corps de diamant (14, 16) contenant une liaison sensible diamant sur diamant et une seconde phase constituée essentiellement de silicium, le silicium étant sous la forme de silicium et/ou de carbure de silicium. 10 15
4. Dispositif de support suivant la revendication 1, caractérisé en ce qu'une ou chacune des surfaces de support de diamant opposées est prévue par la surface (22) d'un corps de diamant (26) qui comprend des particules de diamant autoliées présentes en une quantité de 70 % à 95 % en volume du corps, et un réseau de pores vides, interconnectés, dispersés à travers le corps. 20 25 30
5. Dispositif de support suivant la revendication 1, caractérisé en ce qu'une ou chacune des surfaces de support de diamant opposées est prévue par une surface (22) d'un film de diamant par CVD (26). 35
6. Moteur de forage de trou comprenant un dispositif de support suivant l'une quelconque des revendications 1 à 5 sous la forme d'un support recevant une poussée. 40 45 50

